Run-11 RHIC Polarimetry Analysis

version 0.2

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Abstract

We present results on the measurement of polarization of proton beams in RHIC run 11.

Contents

1 Beam polarization

In 2011 run every attempt was made to collect good data with all RHIC polarimeters in every fill. As the result of this effort, in most of the 2011 fills we have several measurements of the beam polarization $P_{\rm crb}^{(\rm p)}$ (p = B1U, Y1D, B2D, Y2U; p = U, D; or p = B, Y) obtained with the p-Carbon polarimeters and the average fill polarization, $P_{\rm jet}$, from the H-jet polarimeter. Most of the measurement taken with the p-Carbon polarimeters were "sweep" measurements and therefore, corresponding horizontal and vertical beam profiles $R_v^{(\rm p)}$ and $R_h^{(\rm p)}$ are also available. From such measurements we calculate the fill average polarization[1] $\overline{P_{\rm crb}^{(\rm p)}}$ with the corresponding statistical error $\Delta\overline{P_{\rm crb}^{(\rm p)}}$, and the fill average polarization profiles $\overline{R_v^{(\rm p)}}$ and $\overline{R_h^{(\rm p)}}$ for each p-Carbon polarimeter.

While polarization $P_{\rm jet}$ is measured directly the polarization $P_{\rm crb}^{(\rm p)}$ is initially calculated using predictions for the p-Carbon analyzing power based on the 2004 run data [**??**]. We choose not to rely on these estimates but instead we correct on average the p-Carbon numbers to the H-jet value in each fill. The normalization factor $k_{\rm jet/crb}^{(\rm p)}$ is defined by the average ratio over all fills:

$$k_{\rm jet/crb}^{(\rm p)} = \left\langle \frac{P_{\rm jet}}{\overline{P_{\rm crb}^{(\rm p)}}} \right\rangle_{\rm fills} . \tag{1}$$

It will be shown later that the normalization to the H-jet can also account for some systematic effects associated with the measurements by the p-Carbon polarimeters while still allowing one to benefit from the larger statistics. We calculate the correction factors for each of the p-Carbon polarimeters individualy so, formally, the corection for the central value and the statistica error can be written as:

$$\overline{P^{(\rm p)}} \equiv \overline{P_{\rm crb}^{(\rm p)}} \times k_{\rm jet/crb}^{(\rm p)} \qquad \text{and} \qquad \Delta\overline{P^{(\rm p)}} \equiv \Delta\overline{P_{\rm crb}^{(\rm p)}} \times k_{\rm jet/crb}^{(\rm p)} \tag{2}$$

1.1 Beam polarization in a fill

In general, we do not see a reason for using measurements from either upstream or downstream polarimeter alone. Therefore, we calculate the final fill polarization, $\overline{P}$, for each beam by calculating the weighted average of the two p-Carbon polarimeters in the ring:

$$\overline{P} = \frac{\sum\limits_{\rm p=U,D} \overline{P^{(\rm p)}} \left(1/\Delta\overline{P^{(\rm p)}}\right)^2}{\sum\limits_{\rm p=U,D} \left(1/\Delta\overline{P^{(\rm p)}}\right)^2}, \qquad \Delta\overline{P} = \frac{1}{\sqrt{\sum\limits_{\rm p=U,D} \left(1/\Delta\overline{P^{(\rm p)}}\right)^2}} \tag{3}$$

The above equations define the average beam polarization and its error in a fill. However, the physicists analyzing data from the collider experiments STAR and PHENIX are interested in the beam polarization in collisions. This polarization takes into account the intensity profile of the both beams:

$$\overline{P}_{\rm coll} = \frac{\iint \overline{P}(x,y) I^{(\rm B)}(x,y) I^{(\rm Y)}(x,y) dxdy}{\iint I^{(\rm B)}(x,y) I^{(\rm Y)}(x,y) dxdy} \tag{4}$$

Assuming the polarization and intensity profiles have a gaussian shape the relation between $\overline{P}$ and $\overline{P}_{\rm coll}$ can be simply written as:

[1]The better way is to calculate a luminosity weighted average.

$$\overline{P}_{\rm coll} = \overline{P} \times k_{\rm coll} \qquad \text{with} \qquad k_{\rm coll} = \frac{\sqrt{1+\overline{R_h}}\sqrt{1+\overline{R_v}}}{\sqrt{1+\frac{1}{2}\overline{R_h}}\sqrt{1+\frac{1}{2}\overline{R_v}}}. \tag{5}$$

In the calculation of the profile correction factor $k_{\rm coll}$ we use the profile ratios $\overline{R_h}$ and $\overline{R_v}$ averaged over the fill. These quantities are extracted from the fit [**?**].

It is not uncommon for the analyzers to combine a number of fills in order to calculate the average polarization. In this case one should be careful by taking into account the correlation between various components of the total systematic uncertainty on the fill average. In the following we discuss the systematic uncertainties and their correlation in details.

2 Systematic Uncertainties

In this section we discuss the systematic uncertainties associated with the polarizatin measurement by both the p-Carbon and H-jet polarimeters. Not all of the discussed uncertainties directly enter the final result as some can be accounted for indirectly through a proper normalization.

2.1 Uncertainties on p-Carbon polarization

It is clear that due to normalization of the p-Carbon fill average to the H-jet one the final uncertainty on $\overline{P^{\rm (p)}}$ directly depends on the resolution of the H-jet measurement itself. We distinguish the following three sources associated with the measurement by the H-jet.

Normalization to H-jet (global) As an estimate for this uncertainty, $\Delta^{\rm norm}$, we use the statistical uncertainty $\Delta k^{\rm (p)}_{\rm jet/crb}$ on the normalization factor $k^{\rm (p)}_{\rm jet/crb}$. It is a global uncertainty fully correlated between individual fills. Note that for a single fill $\Delta^{\rm norm}$ is simply equal to the statistical error on the H-jet measurement while it decreases as $\frac{1}{\sqrt{N}}$ when the number (N) of considered fills increases. The best estimate of $\Delta^{\rm norm}$ is calculated using the set of all available fills in this run. The ratio of the H-jet to the p-Carbon is shown in Figure 1 and the normalization factors are shown in Table 1.

Table 1: Normalization factors with respect to the 2004 run predictions.

	$k^{\rm (p)}_{\rm jet/crb} \pm \Delta k^{\rm (p)}_{\rm jet/crb}$
B1U	$(0.998 \pm 0.011 \times 0.936) = 0.934$
Y2U	$(1.000 \pm 0.011 \times 0.933) = 0.933$
B2D	$(1.027 \pm 0.013 \times 1.030) = 1.058$
Y1D	$(1.005 \pm 0.015 \times 0.904) = 0.909$

We regard this error as correlated between the two polarimeters in each ring but uncorrelated across the yellow and blue rings. The relative uncertainties are listed in Table 2.

Normalization to H-jet As seen in Figure 1 the ratio $K \equiv P_{\rm jet}/\overline{P^{\rm (p)}_{\rm crb}}$ significantly deviates from a constant for all the polarimeters (among all Y2U has the least significant disagreement). We attribute this inconsistency to systematic effects in the p-Carbon polarimeters due to essentially unknown orientation of the target in each measureent and therefore, carbon energy losses in the target. Another contribution perhaps comes from a nonuniform motion of the target through the beam. We assume that the nature and the scale of such systematic effects do not vary significantly from fill to fill and thus, we estimate the overal systematic contribution by solving the following equation for σ^{norm}:

$$\frac{1}{N}\sum_i \frac{(K_i - k^{(\mathrm{p})}_{\mathrm{jet/crb}})^2}{(\sigma^2_{K_i} + (\sigma^{\mathrm{norm}})^2)} = 1 \tag{6}$$

We regard this error as uncorrelated across the polarimeters and individual measurements. The common relative uncertainties for all fills are listed in Table 2.

H-jet molecular background The average polarization values P_{jet} rely on the hydrogen jet target polarization as measured by a Breit-Rabi polarimeter. The jet target is believed to be contaminated with molecular hydrogen whose polarization is unknown (???). A special study was performed to estimate the error on the P_{jet} in 200X [**??**]. In the current analysis we use the value of $\Delta^{\mathrm{mol}}_{\mathrm{jet}} = 2\%$ obtained for 250 GeV beams.
We regard this error as correlated between the yellow and blue beams.

Other H-jet background The error $\Delta^{\mathrm{bkg}}_{\mathrm{jet}}$ represents the uncertainty due to other backgrounds contributing to the measurement of P_{jet}. As the H-jet measures polarization of the two beams simultaneously, it is believed that the main cotribution comes from the interference between the two beams. We did not estimate this unceratainty in 2011, instead we use the value of 3% as was defined in the previous runs.
We regard this error as correlated between the yellow and blue beams.

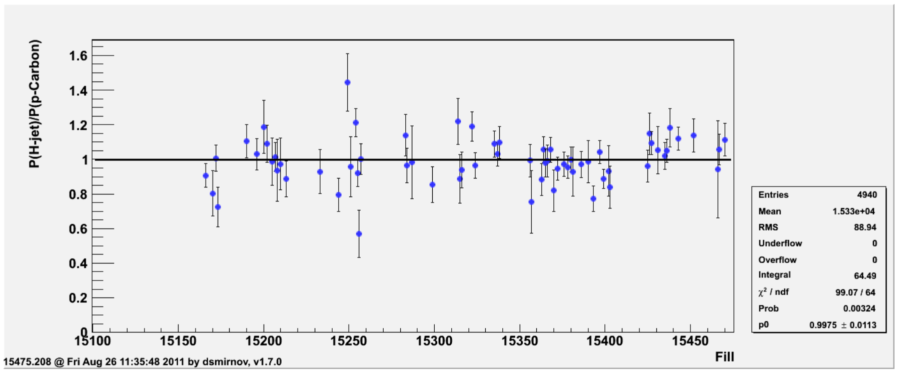
Polarization profile In 2011 run we also observe a systematic shift in the central polarization values as determined directly from a standard sweep measurement and a corresponding value extracted from the polarization *vs.* intensity fit. The bias is believed to be caused by the fact that the target does not exactly follow the uniform motion of the frame when crossing the beam. Instead, the target may be electrostatically attracted to the beam center leading to an incorrect weighting of the collected events. We believe that the polarization extracted from the fit represents a more accurate estimate of the true beam polarization. To account for this inconsistency we introduce another scale factor $k^{(\mathrm{p})}_{\mathrm{prfl/swp}}$ defined as

$$k^{(\mathrm{p})}_{\mathrm{prfl/swp}} = \left\langle \frac{\overline{\mathcal{P}^{(\mathrm{p})}_{\mathrm{crb}}}}{\overline{P^{(\mathrm{p})}_{\mathrm{crb}}}} \right\rangle_{\mathrm{fills}}, \tag{7}$$

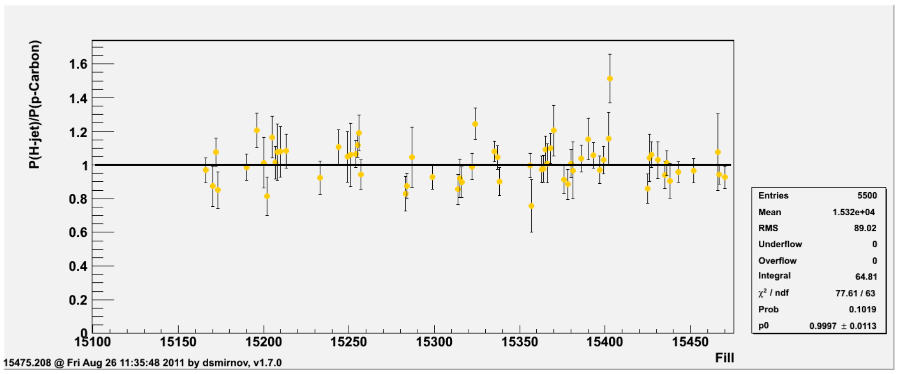
where $\overline{\mathcal{P}^{(\mathrm{p})}_{\mathrm{crb}}}$ is the polarization extracted from the polarization *vs.* intensity fit.

Table 2: Summary of the relative systematic uncertainties for the p-Carbon polarimeters.

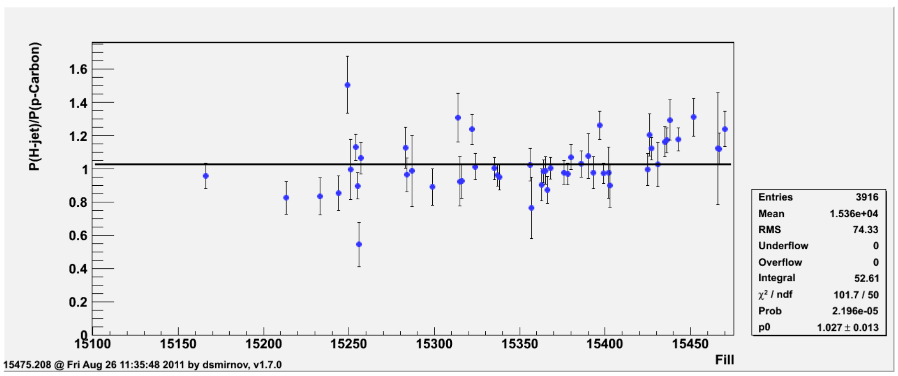
	B1U	**Y2U**	**B2D**	**Y1D**
Δ^{norm}, %	1.1	1.1	1.2	1.5
σ^{norm}, %	7.0	5.4	10.1	6.3



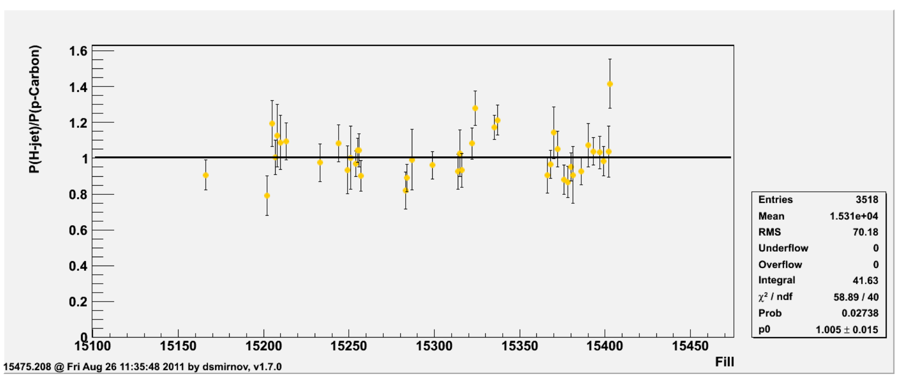
(a) Blue-1 Upstream



(b) Yellow-2 Upstream

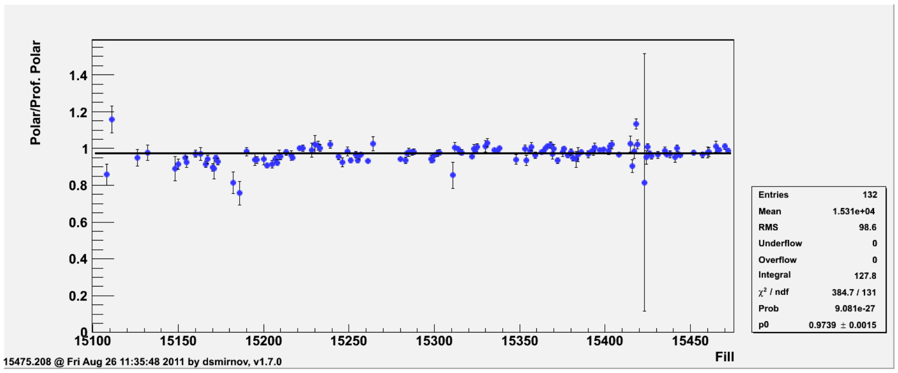


(c) Blue-2 Downstream

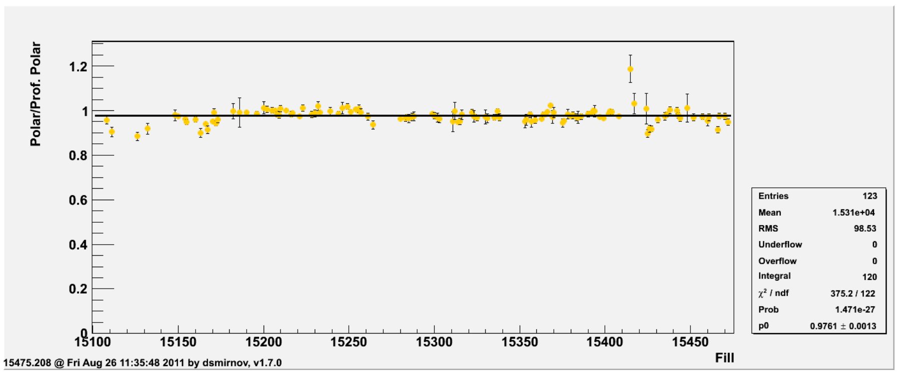


(d) Yellow-1 Downstream

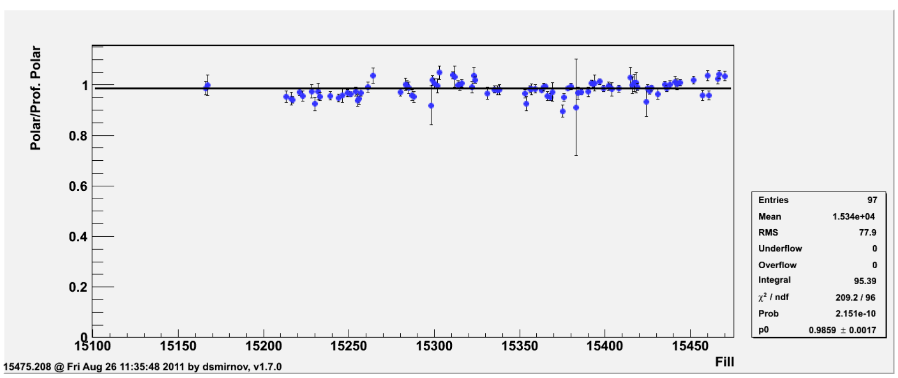
Figure 1: The ratio of $P_{\rm jet}$ and $\overline{P^{(\rm p)}_{\rm crb}}$.



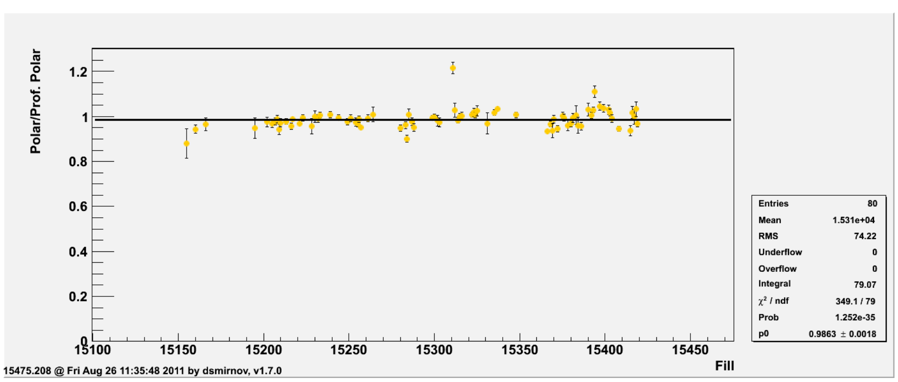
(a) Blue-1 Upstream



(b) Yellow-2 Upstream



(c) Blue-2 Downstream



(d) Yellow-1 Downstream

Figure 2: The ratio of $\overline{\mathcal{P}^{(\mathrm{p})}_{\mathrm{crb}}}$ and $\overline{P^{(\mathrm{p})}_{\mathrm{crb}}}$.

Summary The global systematic uncertainties which propagate to the final beam polarization.

$$\Delta = \Delta^{\text{norm}} \oplus \Delta^{\text{mol}}_{\text{jet}} \oplus \Delta^{\text{bkg}}_{\text{jet}}$$

2.2 Uncertainties on beam polarization in a fill

Upstream vs downstream polarimeter In the fills where measurements from the two polarimeters in the same ring are available we observe non-statistical variations in the measurements even when they closely follow each other in time. At the moment, the observed fluctuations cannot be associated with a single source or a known difference in the devices therefore, we assign a systematic error, $\Delta^{\text{U vs D}}$, on the fill average. We estimate the systematic uncertainty of this kind by calculating the difference between the fill average as measured by the two polarimeters. From Figure **??** the average difference is XXX. In order to cover most of our measurements we conservatively assign $\Delta^{\text{U vs D}} = XXX$.
We regard this error as uncorrelated between the yellow and blue beams.

2.3 Uncertainties on beam polarization in collisions

We define error Δ^{R} as an error on the average fill polarization in collisions $\overline{P}_{\text{coll}}$. This is not a systematic error but rather a propagation of the statistical errors on the measured quantities $\overline{R_h}$ and $\overline{R_v}$ according to equations (5). As one can see on Figure **??** the statistical errors on $\overline{R_h}$ and $\overline{R_v}$ are quite large and systematic effects are not clearly visible as they must be on the same or smaller level as statistical fluctuations. For now we use the statistical error as the total uncertainty on $\overline{R_h}$ and $\overline{R_v}$ leaving the estimation of the systematic effects for the future analysis. We regard this error as uncorrelated between the yellow and blue beams.

Summary For the sources of systematic uncertainties discussed above the total errors on the average fill polarization can be written as:

$$\Delta\overline{P} = \underset{\text{stat}}{\Delta}\,\overline{P} \oplus \overline{P} \times \Delta^{\text{U vs D}} \tag{8}$$

$$\Delta\overline{P}_{\text{coll}} = \underset{\text{stat}}{\Delta}\,\overline{P}_{\text{coll}} \oplus \overline{P}_{\text{coll}} \times \left(\Delta^{\text{U vs D}} \oplus \Delta^{\text{R}}\right) \tag{9}$$

and for the average over a subset of selected fills we have:

$$\Delta\left\langle\overline{P}\right\rangle_{\text{fills}} = \left\langle\Delta\overline{P}\right\rangle_{\text{fills}} \oplus \left\langle\overline{P}\right\rangle_{\text{fills}} \times \left(\Delta^{\text{norm}} \oplus \Delta^{\text{mol}}_{\text{jet}} \oplus \Delta^{\text{bkg}}_{\text{jet}}\right) \tag{10}$$

$$\Delta\left\langle\overline{P}_{\text{coll}}\right\rangle_{\text{fills}} = \left\langle\Delta\overline{P}_{\text{coll}}\right\rangle_{\text{fills}} \oplus \left\langle\overline{P}_{\text{coll}}\right\rangle_{\text{fills}} \times \left(\Delta^{\text{norm}} \oplus \Delta^{\text{mol}}_{\text{jet}} \oplus \Delta^{\text{bkg}}_{\text{jet}}\right) \tag{11}$$

2.4 Uncertainty on single spin asymmetry

For measurements of the single spin asymmetry the experiments use the average of the two beam polarizations $\frac{\langle P^{(\text{B})}\rangle + \langle P^{(\text{Y})}\rangle}{2}$. The total uncertainty is then calculated using the values in Table**??** for different beams. Taking into account the proper correlation between the two beams we obtain:

$$\Delta = \frac{1}{2} \times (\Delta^{\text{norm}})^{(\text{B})} \oplus (\Delta^{\text{norm}})^{(\text{Y})} \oplus \left((\Delta^{\text{mol}}_{\text{jet}})^{(\text{B})} + (\Delta^{\text{mol}}_{\text{jet}})^{(\text{Y})}\right) \oplus \left((\Delta^{\text{bkg}}_{\text{jet}})^{(\text{B})} + (\Delta^{\text{bkg}}_{\text{jet}})^{(\text{Y})}\right) \tag{12}$$

2.5 Uncertainty on double spin asymmetry

Similarly, the double spin asymmetry measurements use the product of two beam polarization $\langle P^{(\mathrm{B})} \rangle \times \langle P^{(\mathrm{Y})} \rangle$. The total unceratainty in this case is:

$$\Delta = (\Delta^{\mathrm{norm}})^{(\mathrm{B})} \oplus (\Delta^{\mathrm{norm}})^{(\mathrm{Y})} \oplus \left((\Delta^{\mathrm{mol}}_{\mathrm{jet}})^{(\mathrm{B})} + (\Delta^{\mathrm{mol}}_{\mathrm{jet}})^{(\mathrm{Y})} \right) \oplus \left((\Delta^{\mathrm{bkg}}_{\mathrm{jet}})^{(\mathrm{B})} + (\Delta^{\mathrm{bkg}}_{\mathrm{jet}})^{(\mathrm{Y})} \right) \tag{13}$$